THE USE OF MULTI-RESOLUTION ENVIRONMENTS IN SIMULATIONS: EXPERIENCES FROM ARGONNE NATIONAL LABORATORY

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BRIEFING OUTLINE

- Why Are Multi-Resolution Environmental Representations Required?

- Argonne Applications Involving Multi-Resolution Environmental Representations

- Approaches Being Implemented to Provide Seamless, Multi-Resolution Environmental Representation

- Summary and Conclusions

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WHY ARE MULTI-RESOLUTION ENVIRONMENTAL REPRESENTATIONS REQUIRED?

- Physics and Military Commanders Don't Obey PDUs
  - Physics Processes are Spatially (and Temporally) Dependent and can be Highly Dynamic

  - Military Commanders Must Take Into Account Developments at all Spatial Levels

- Environmental Data are Not Always Available at the Same Spatial Resolution

ARGONNE APPLICATIONS INVOLVING MULTI-RESOLUTION ENVIRONMENTAL REPRESENTATIONS

- DOE: Scene Rendering of DOE Sites With Automatic Variable Spatial Resolution

- USAF AWS: Nested Grids for Weather Forecasts

- JWARS: Terrain Representations at Different Resolutions and Topologies

- JSIMS/JTFp: Atmospheric and Terrain Reprsentations at Different Spatial Resolutions

- SFWMD/USA COE - Hydrological Modeling Involving Spatial Representations of Variable Sizes and Topologies in 2- and 3-Dimensions With User Definable Grid/Cell Definitions

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ARGONNE APPLICATIONS INVOLVING MULTI-RESOLUTION ENVIRONMENTAL REPRESENTATIONS

Variable Spatial Resolution Provides the Resolution Required For a Given Application

ARGONNE CONCLUSIONS REGARDING MULTI-RESOLUTION ENVIRONMENTAL REPRESENTATIONS

- <u>Bottom Line</u>: One Size Does Not Fit All - Nor Should It

- In Order for Simulations to be Responsive to Users Needs, the Simulation Must be Able to Utilize Variable and Mutiple Spatial Resolutions That:
  - Can Automatically Respond to the Context of the Simulation (*i.e.* Know How to Obtain and Apply State Variables)

  - Can Respond to User Instructions

- Argonne's Approach is to Utilize a Software Infrastructure Object, the Spatial Data Set Object, for all Datasets Which Associates Data Structures With Specific Regions or Points in 2- or 3-D Space
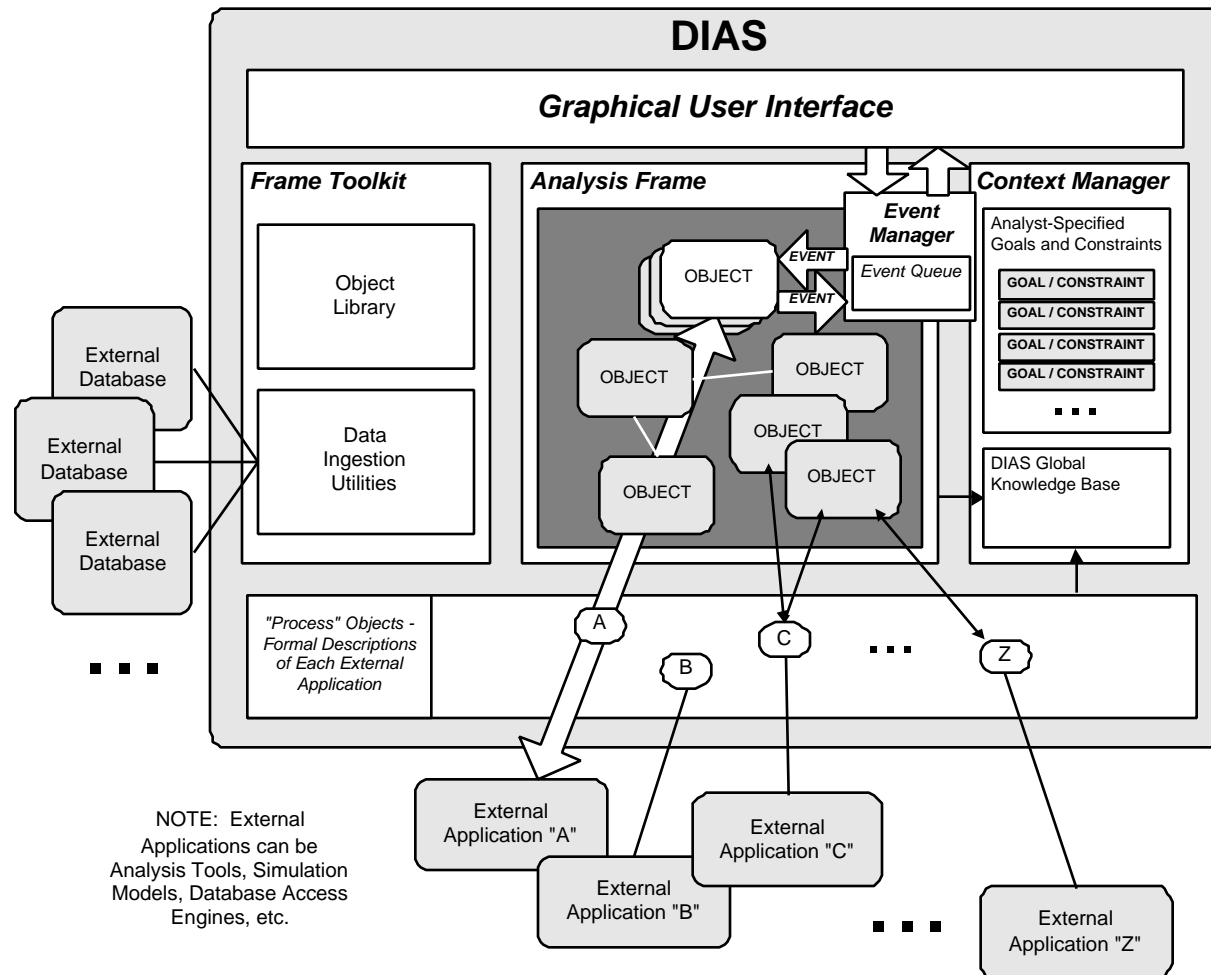
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DIAS PURPOSE AND DESIGN GOALS

- DIAS Is Intended As a Software Framework Within Which New or Existing "Legacy" Software Applications (Simulation Models, Database Access Engines, Etc.) Can Operate Harmoniously in the Same Frame of Reference to Address an Analyst's Concerns.

- To Enable It to Fulfill This Role, the DIAS Software Architecture Must Be Able to:
  - Provide a Flexible Mechanism to Allow Disparate Software Applications to Interoperate.

  - Capture the Dynamic Interplay Between Several Different Processes/Phenomena Operating Simultaneously in the Same Frame of Reference.

  - Accommodate a Broad Range of Analysis Contexts, with Widely Varying Resolution and Fidelity.

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DIAS SCHEMATIC DIAGRAM

DIAS

Graphical User Interface

Frame Toolkit

Object Library

Data Ingestion Utilities

Analysis Frame

OBJECT

OBJECT

OBJECT

OBJECT

OBJECT

OBJECT

EVENT

EVENT

Event Manager

Event Queue

Context Manager

Analyst-Specified Goals and Constraints

GOAL / CONSTRAINT

GOAL / CONSTRAINT

GOAL / CONSTRAINT

GOAL / CONSTRAINT

. . .

DIAS Global Knowledge Base

External Database

External Database

External Database

. . .

"Process" Objects - Formal Descriptions of Each External Application

A

B

C

. . .

Z

NOTE: External Applications can be Analysis Tools, Simulation Models, Database Access Engines, etc.

External Application "A"

External Application "B"

External Application "C"

. . .

External Application "Z"

DEEM SPATIAL DATA SET OBJECTS

- The Spatial Data Set Object is the Abstract Object Superclass for all DEEM/DIAS Datasets Which Associate Data Structures with Specific <u>Regions</u> (Cells) or Points (PCells) in 2- or 3-Dimensional Space.

- Cell / PCell Data Dictionary is Flexible.

- The Same <u>Data </u>Dictionary (Not Data <u>Content)</u> is Used for Every Cell / PCell Within the SpatialDataSet.

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DEEM SPATIAL DATA SET OBJECTS: USES

- Spatial Data Set Objects Have Two Major Areas of Application Within DEEM/DIAS:

  – When Referenced From Within Entity Objects, They can Carry the Entity State Data That are Spatially Varying

  – When Carried in Projection Objects, They can Move Complex Bodies of Spatially Referenced Information, Complete with Their Spatial Contexts, Back and Forth Between Entities and External or Internal Modeling and Analysis Applications.

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DEEM SPATIAL DATA SET OBJECTS: SUBCLASSES

- The Spatial Data Set Object has Many Subclasses Covering Different Modes of Spatial Partitioning:
  - Cells (Values Apply Within a Region)
    - » Cells Bounded by Faces
    - » Faces may also Carry Data in Addition to Geometries
  - Points (Values Apply at a Point)
  - 2D / 3D
  - Several Different Topologies and Geometries Considered

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DEEM SPATIAL DATA SET OBJECTS: CELL SET SUBCLASSES

2-D Cell Sets

3-D Cell Sets

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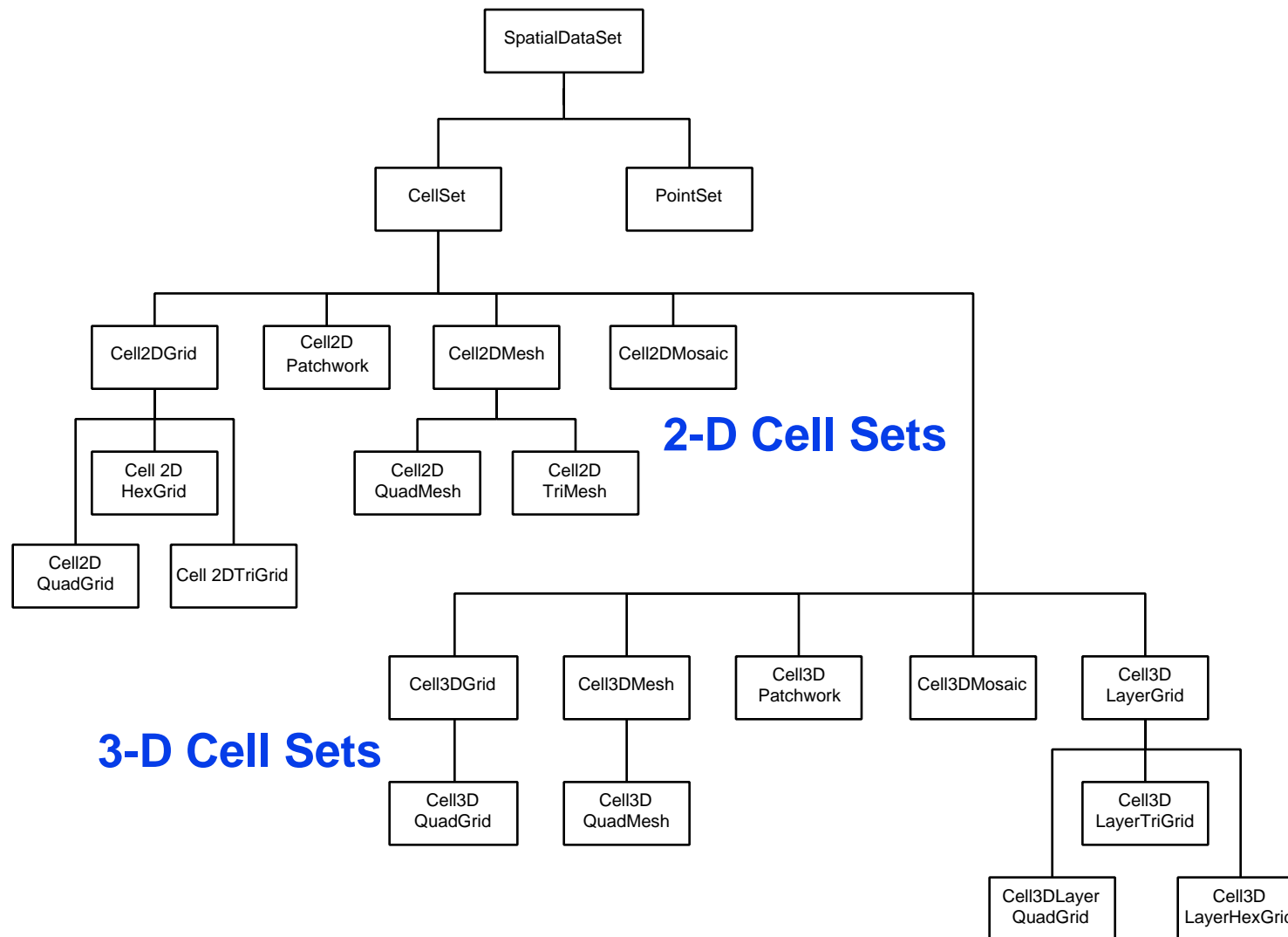
DEEM SPATIAL DATA SET OBJECTS: POINT SET SUBCLASSES

2-D Point Sets

3-D Point Sets

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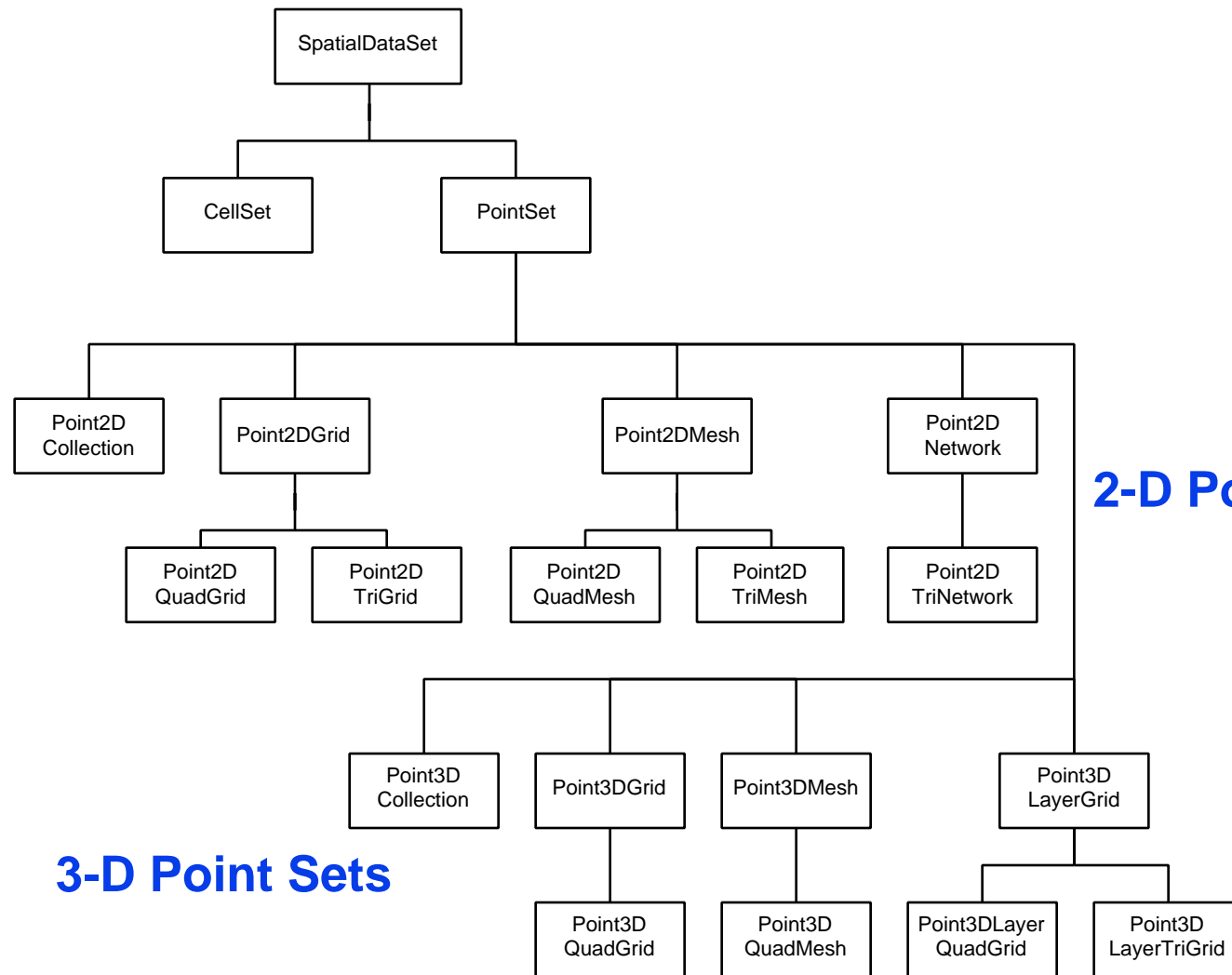
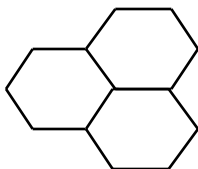# DEEM SPATIAL DATA SET OBJECTS: CELL SETS

Cell2DSets
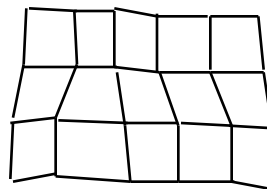
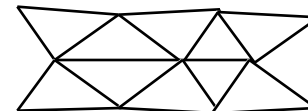### Grid (Identical Cells)
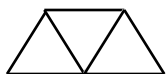
Quad   Tri   Hex
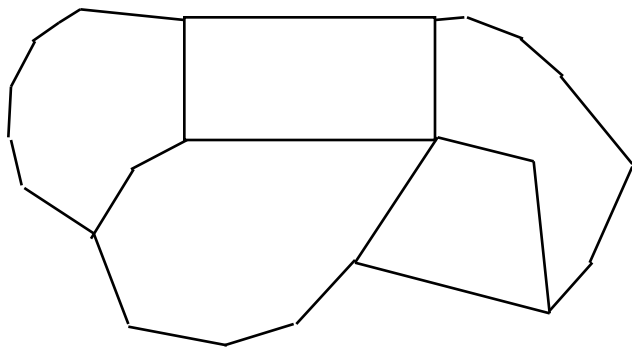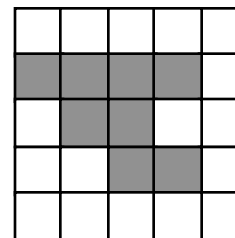
Mesh (Distorted Cells)

Quad   Tri

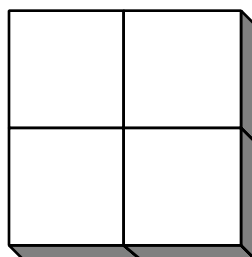### Patchwork (Polygonal Cells)

Mosaic ("Rasterized" or "Pixel Cells")
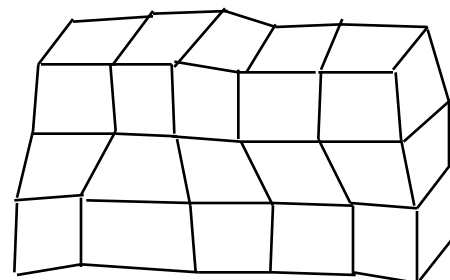
DEEM SPATIAL DATA SET OBJECTS: CELL SETS

Cell3DSets

Grid (Identical Cells)
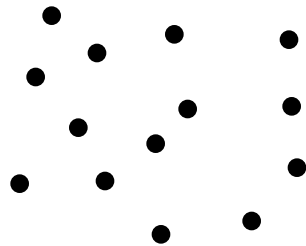Quad

Mesh (Distorted Cells)
Quad

- Patchwork (Polygonal Cells)

- Mosaic ("Voxelized Cells")

- LayerGrid (Stack of 2D Grids)

DEEM SPATIAL DATA SET OBJECTS:
POINT SETS

Point2DSets

Collection ("Scatter-Plot")

Grid (Evenly Spaced)
Quad   Tri
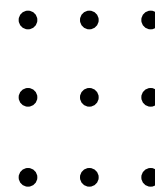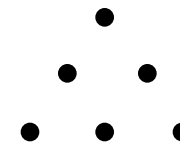
Mesh (Distorted Grid)
Quad   Tri

Network
Tri

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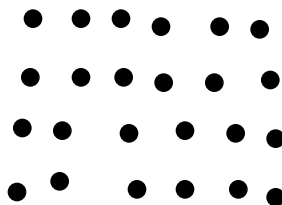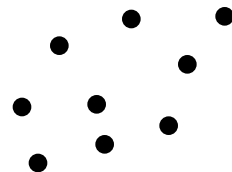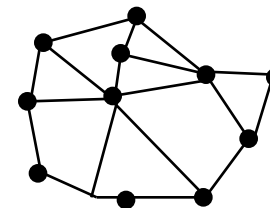
DEEM SPATIAL DATA SET OBJECTS: POINT SETS

- **Point3DSets**
  - Collection
  - Grid   ...Quad
  - Mesh   ...Quad
  - LayerGrid (Stack of 2D Grids)   ...Quad, Tri

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DEEM SPATIAL DATA SET SUBCLASSES

Cell2DGrid

Coord. Sys. Specs.

Cell Data Dictionary

Face Locus Table

Face Data Dictionary

SubGrid Partition Specs.

Cell Array

i

j

Cell ptr
Face ptrs

(Cell and Face coordinates and geometries are based on i, j, and the Face Locus Table.)

Cell

Private Data

----

subGrid ptr

Cell2DSubgrid

nest level

Cell Array

i

j

Cell ptr
Face ptrs

Cell2DGrid Subclasses:
- Cell2DQuadGrid
- Cell2DTriGrid
- Cell2DHexGrid

Face

Private Data

Cell ptrs

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DEEM SPATIAL DATA SET SUBCLASSES: CELL2DGRID

Cell2DGrid

Coord. Sys. Specs.

Cell Data Dictionary.

Face Data Dictionary.

Cell Quadtree

Cell

Private Data

Face List

Face ptr | Direction

**Cell2DPatchwork
Subclasses:
- none -**

Face

Locus Vertex List

Vertex ptr.

Private Data

Cell ptrs

DEEM SPATIAL DATA SET SUBCLASSES: POINT3DGRID

Point3DGrid

Coord. Sys. Specs.

PCell Data Dictionary

SubGrid Partition Specs.

PCell Array

i

k

PCell ptr (x,y,z)*

j

(*PCell x, y & z are derivable from i, j & k)
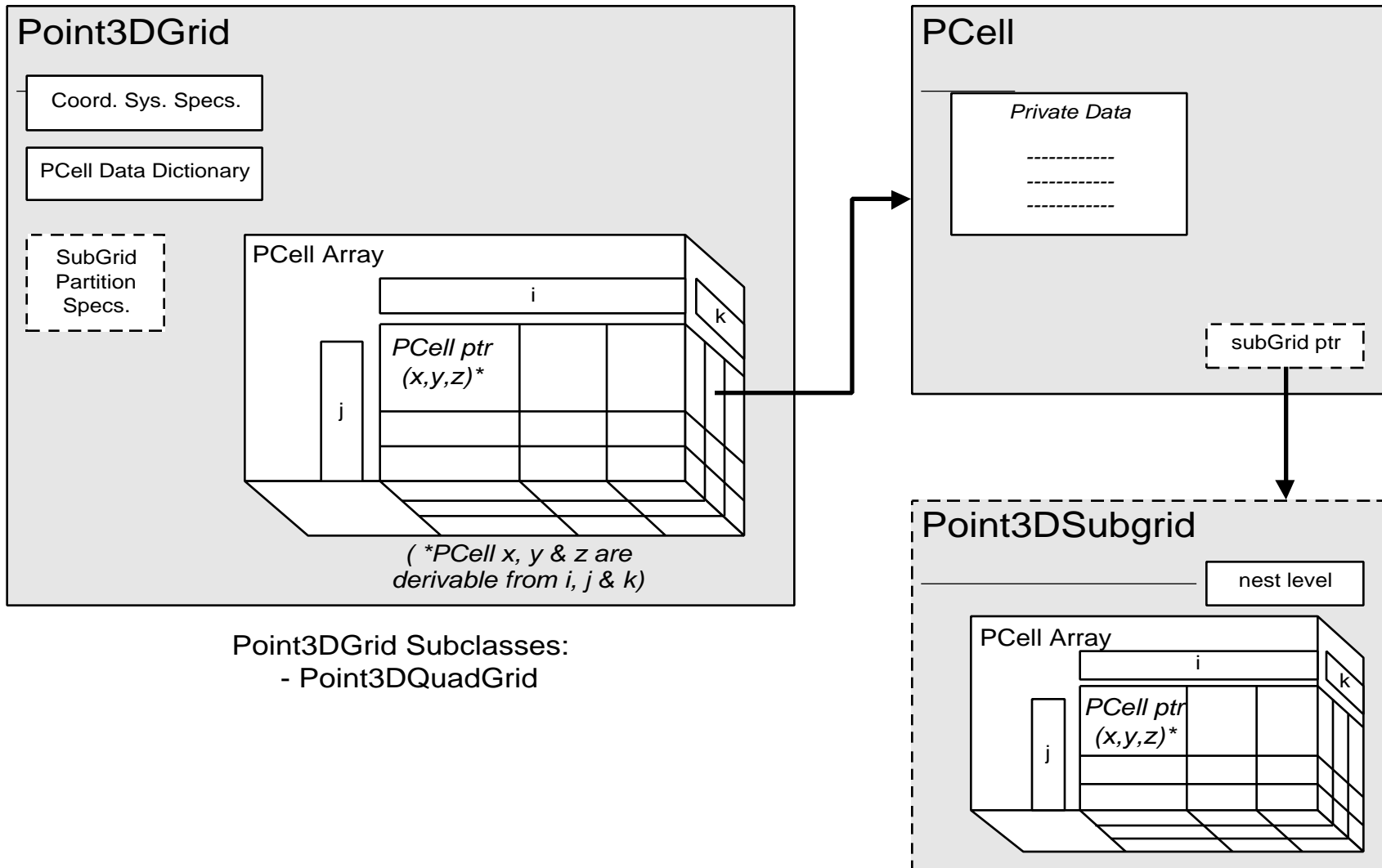
Point3DGrid Subclasses:
- Point3DQuadGrid

PCell

Private Data

----

subGrid ptr

Point3DSubgrid

nest level

PCell Array

i

k

PCell ptr (x,y,z)*

j

USING THE SPATIAL DATA SET OBJECT WITH THE DEEM ATMOSPHERE OBJECT

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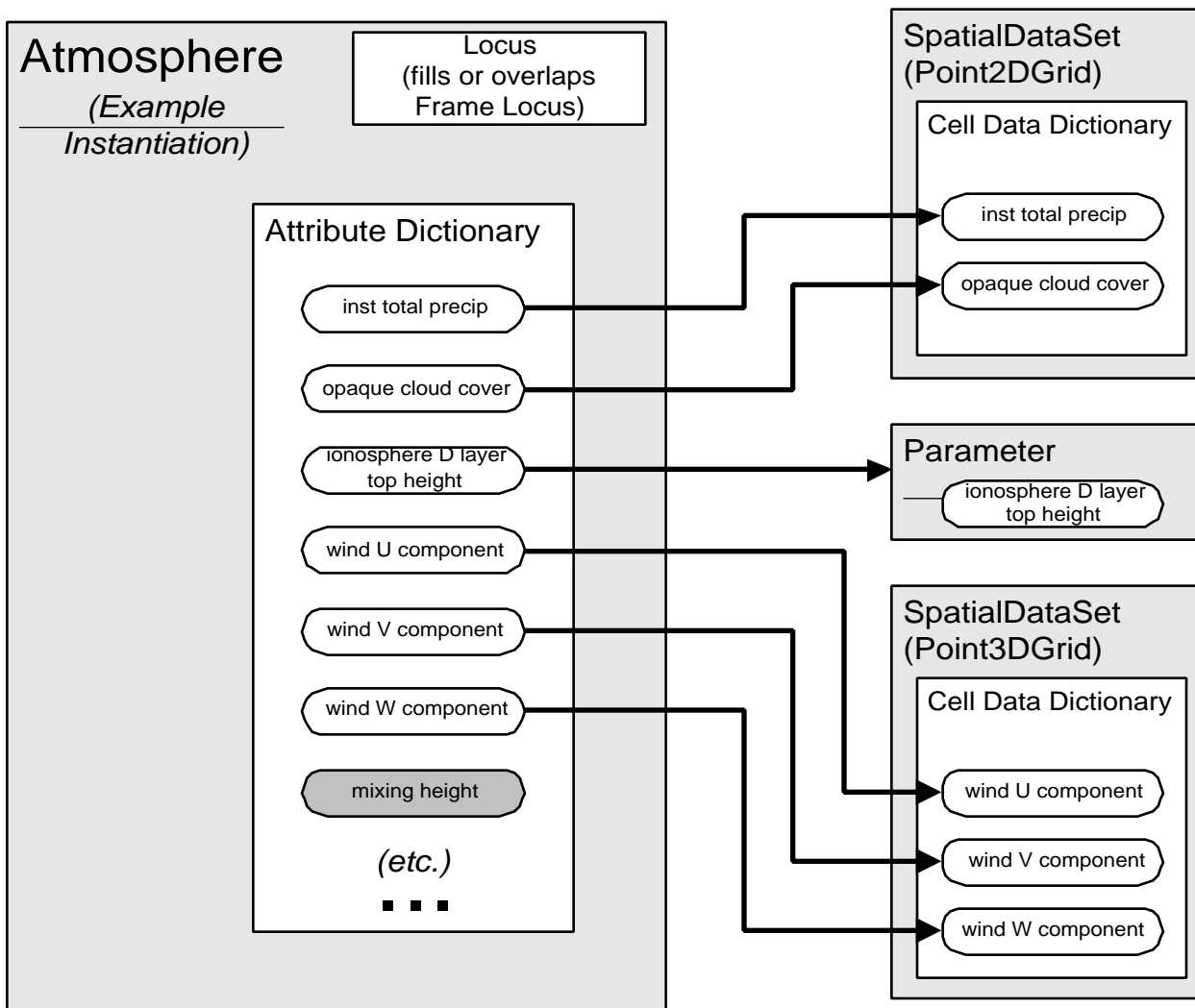
USING THE SPATIAL DATA SET OBJECT WITH THE DEEM EARTH SURFACE OBJECT

Surface Cover in native vector polygon form

Surface Cover and terrain height, gridded for use by a weather model

SpatialDataSet (Cell2DPatchwork)
- Cell Data Dictionary
  - surface cover type
  - aerodynamic surface roughness

Projection
- SpatialDataSet (Point2DGrid)
  - Cell Data Dictionary
    - surface cover type
    - terrain elevation

EarthSurface
(Example Instantiation)

Locus (fills Frame Locus)

HydroNet List
- HydroNet ptr

Attribute Dictionary
- surface cover type
- aerodynamic surface roughness
- terrain elevation
- ponding depth
- field moisture holding capacity
- groundwater level

(etc.)

SpatialDataSet (Point2DTriNetwork)
- terrain elevation

Topographic data, in Triangulated Irregular Network (TIN) form

SpatialDataSet (Cell2DPatchwork)
- Cell Data Dictionary
  - ponding depth
  - field moisture holding capacity
  - groundwater level

Surface and groundwater hydrologic data, partitioned into polygonal cells for the SFRSM

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USING THE SPATIAL DATA SET OBJECT IN HYDROLOGICAL MODELING

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In this example, StreamCrossSections have been interpolated to Cell boundaries to support MODBRANCH; the original StreamCrossSections are omitted for clarity.

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SUMMARY AND CONCLUSIONS

- The Real Physical and Military World Do Not Respond to a Single Spatial Resolution and so the Use of Multiple and Dynamic Spatial Resolutions is Required in Simulations

- Multiple Resolution Environmental Representations Must Be Applied Seamlessly and In Response to the Context of the Simulation as Well as User Directions

- Argonne National Laboratory has Developed a Spatial Data Set Object for Use With Spatial Datasets That Associates Data Structures With Specific Spatial Representations

- The Use of the Spatial Data Set Object Provides a Flexible Mechanism to Utilize the Spatial Repsentation Best Suited to the Simulation and the Users Goals and Constraints

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